Overview Of

Clean Burning Fuels with Oxygenates

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February 1999

Fuel Quality Factors for Cleaner Burning Gasolines

Sulfur reductions are more important for controlling emissions during the vehicle's "hot cycle"

Limiting distillation temperatures and aromatic content are the most important parameters for controlling emissions during the vehicle's" cold cycle", & build-up of Combustion Chamber Deposits (CCD's)

Adding "oxygenates" to gasoline is one of the most effective means for both decreasing aromatics and distillation temperatures (Clean Burning Octane)

Congress used the Oxygen Standard in RFG to require the use of Clean Burning Oxygenates for Octane, not because the oxygen by itself made gasoline cleaner burning

Fuel Quality Factors for Cleaner Burning Gasolines

Need "Full" Vaporization During Cold Engine Operation

- Partial Vaporiztion increases unburned hydrocarbons
- Hydrocarbons boiling above 210 F contribute to poor vaporization
- Low T50 distillation temperatures allow more complete combustion prior to engine warm-up

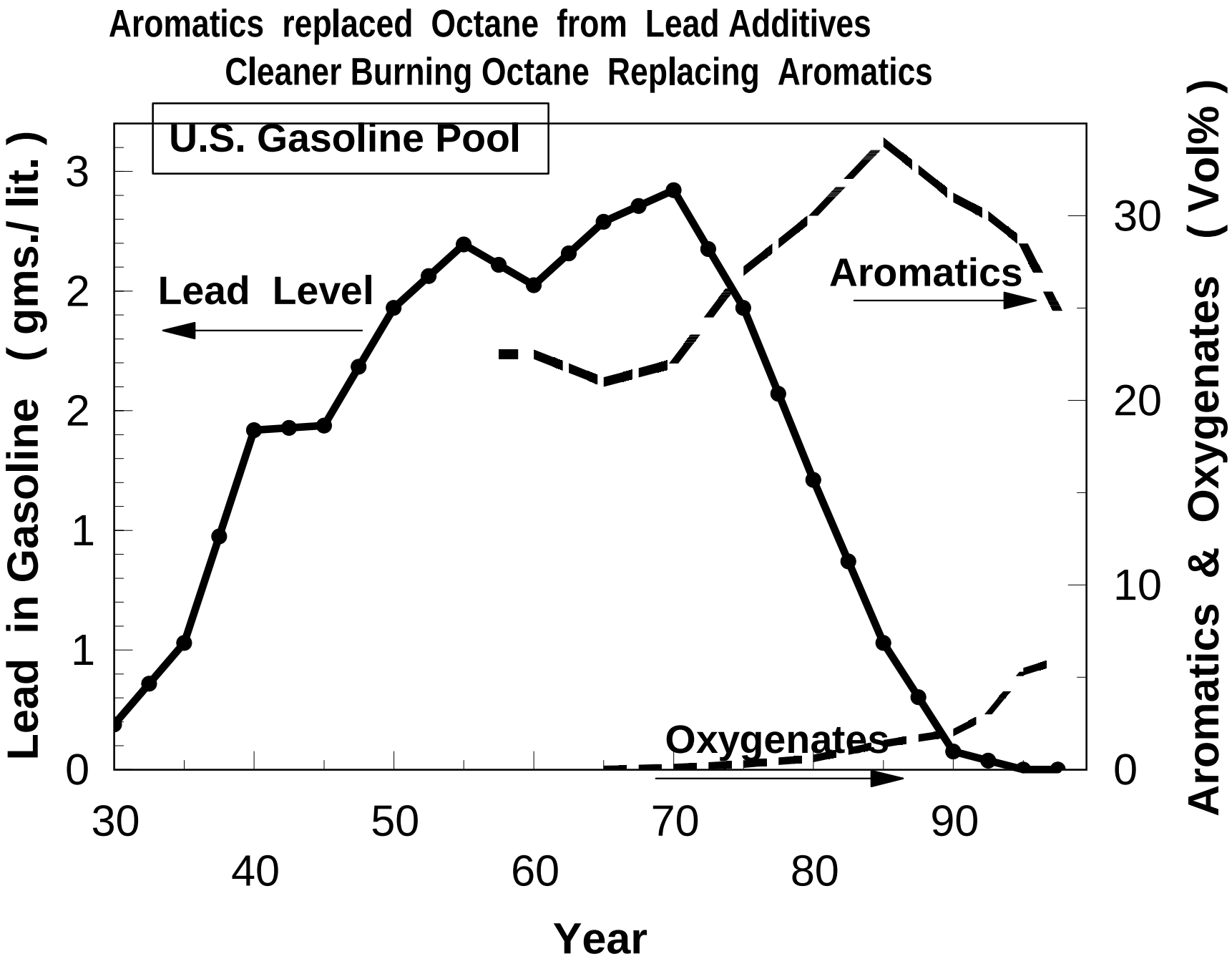
Aromatics oxidize to larger, condensable molecules

- Leads to increased combustion chamber deposits
- Increases Primary PM in Exhaust
- Some of the unburned aromatics oxidize to larger secondary organic aerosols (PM) in the atmosphere

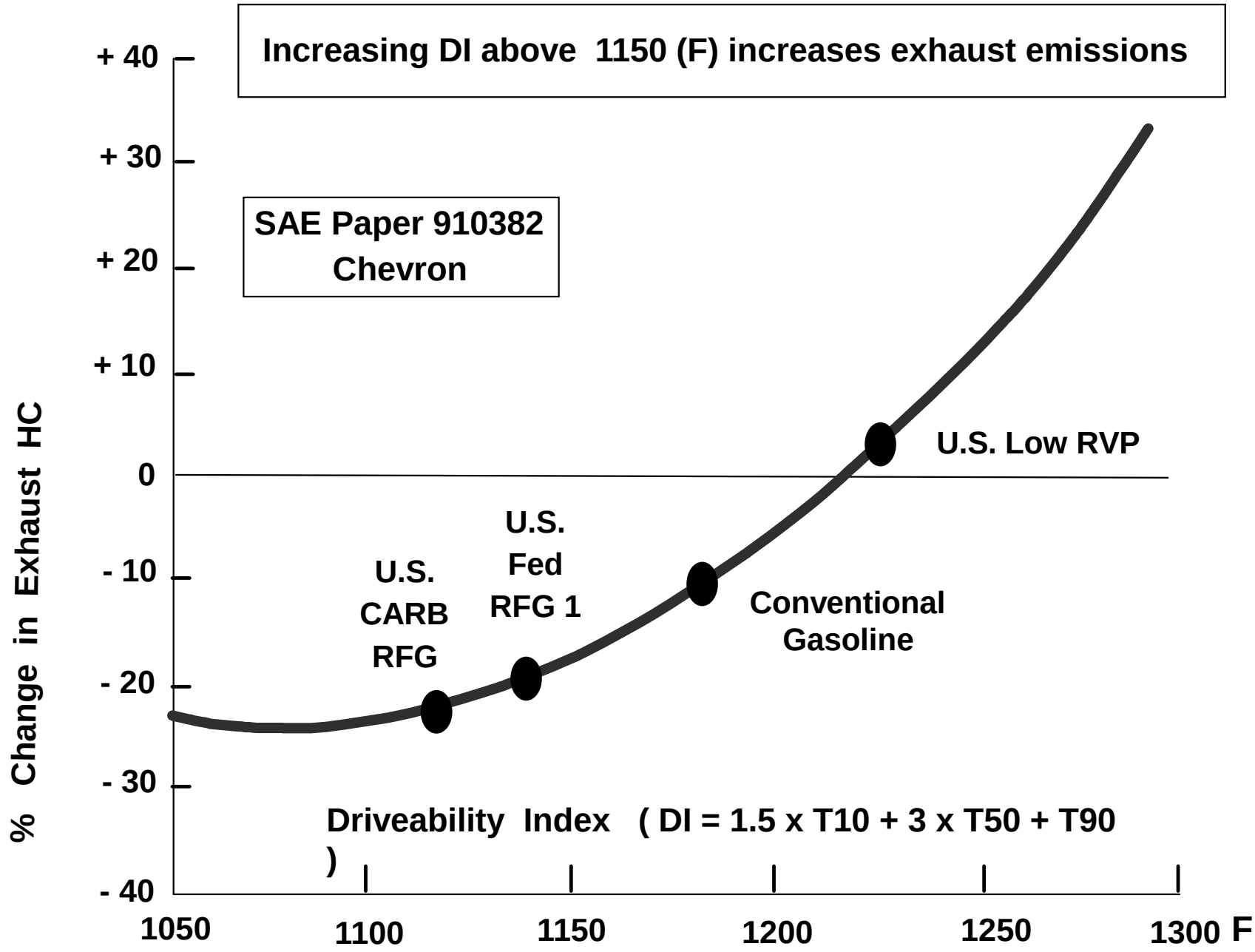
Unburned aromatics very reactive for "peak ozone" formation

CO2 emissions per Km increases with increasing aromatics

Lower sulfur only improves cat converter efficiency, but not combustion efficiency or engine-out emissions

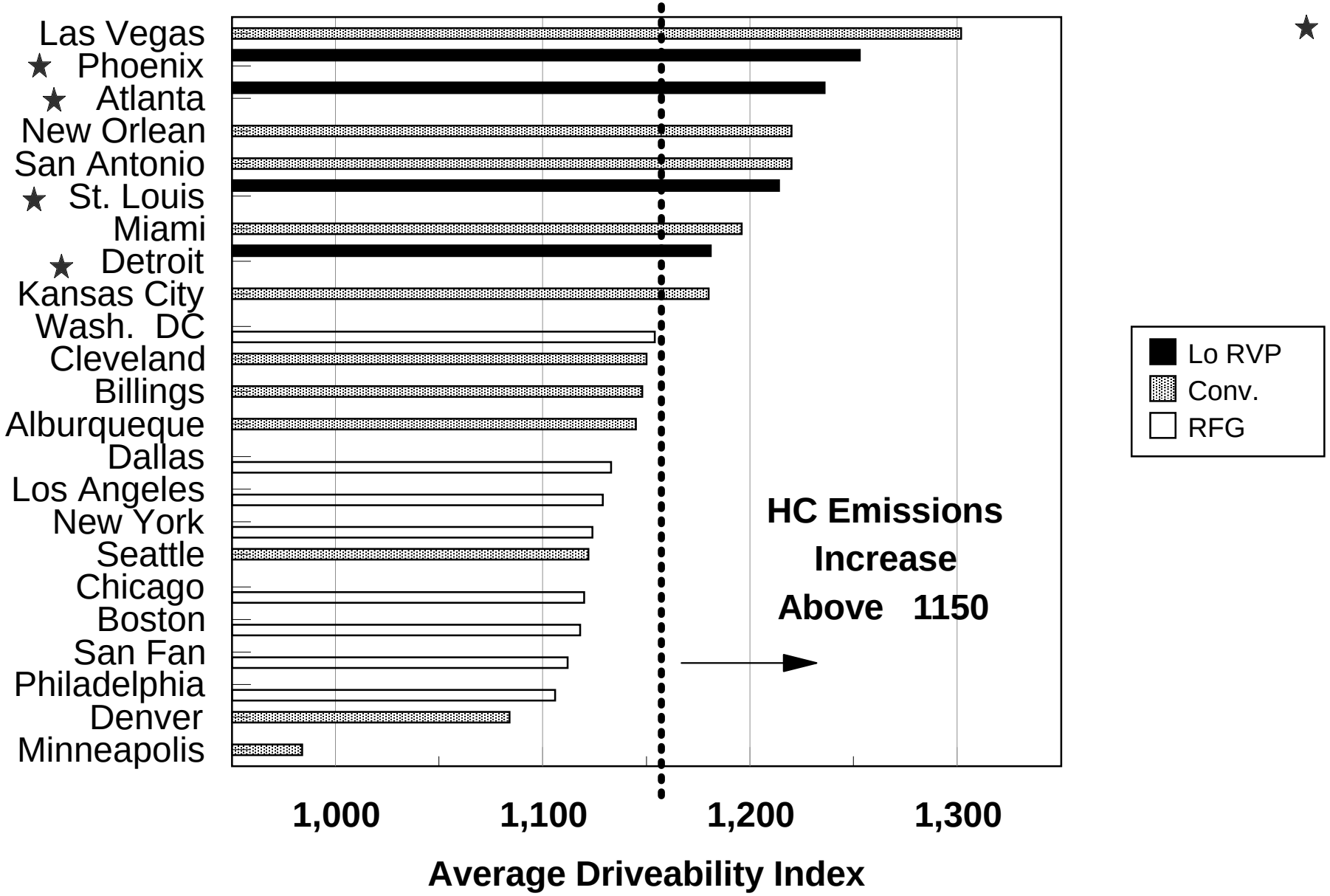

Aromatics replaced Octane from Lead Additives
Cleaner Burning Octane Replacing Aromatics
U.S. Gasoline Pool
Lead Level
Aromatics
Oxygenates
Lead in Gasoline (gms./ lit.)
Aromatics & Oxygenates (Vol%)
Year
0
1
1
2
2
3
0
10
20
30
30
40
50
60
70
80
90

Various Studies Show that High Boiling Gasoline Increases Exhaust HC

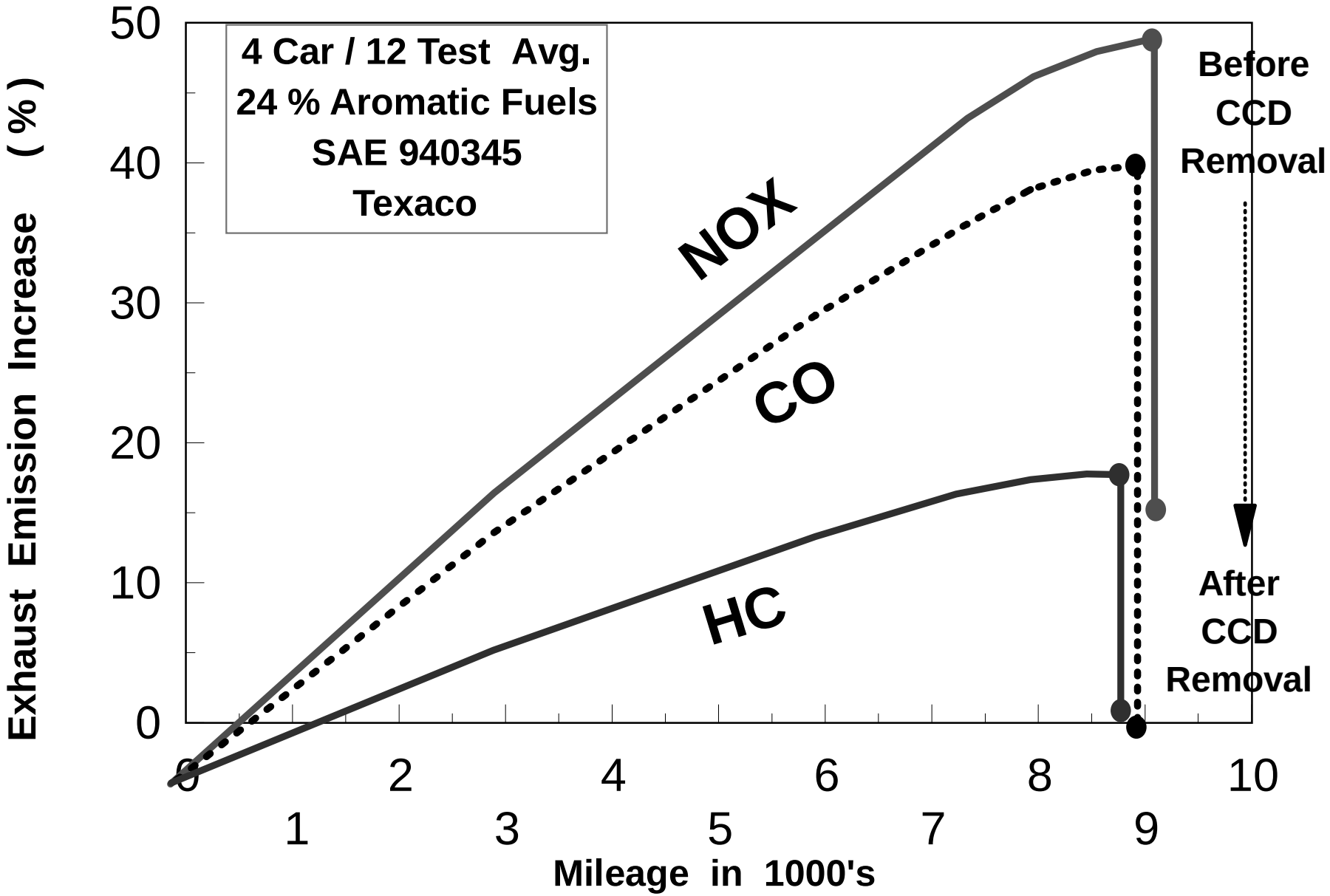


Low RVP Contributes to Higher DI Fuels

1996 Summer Regular Gasoline

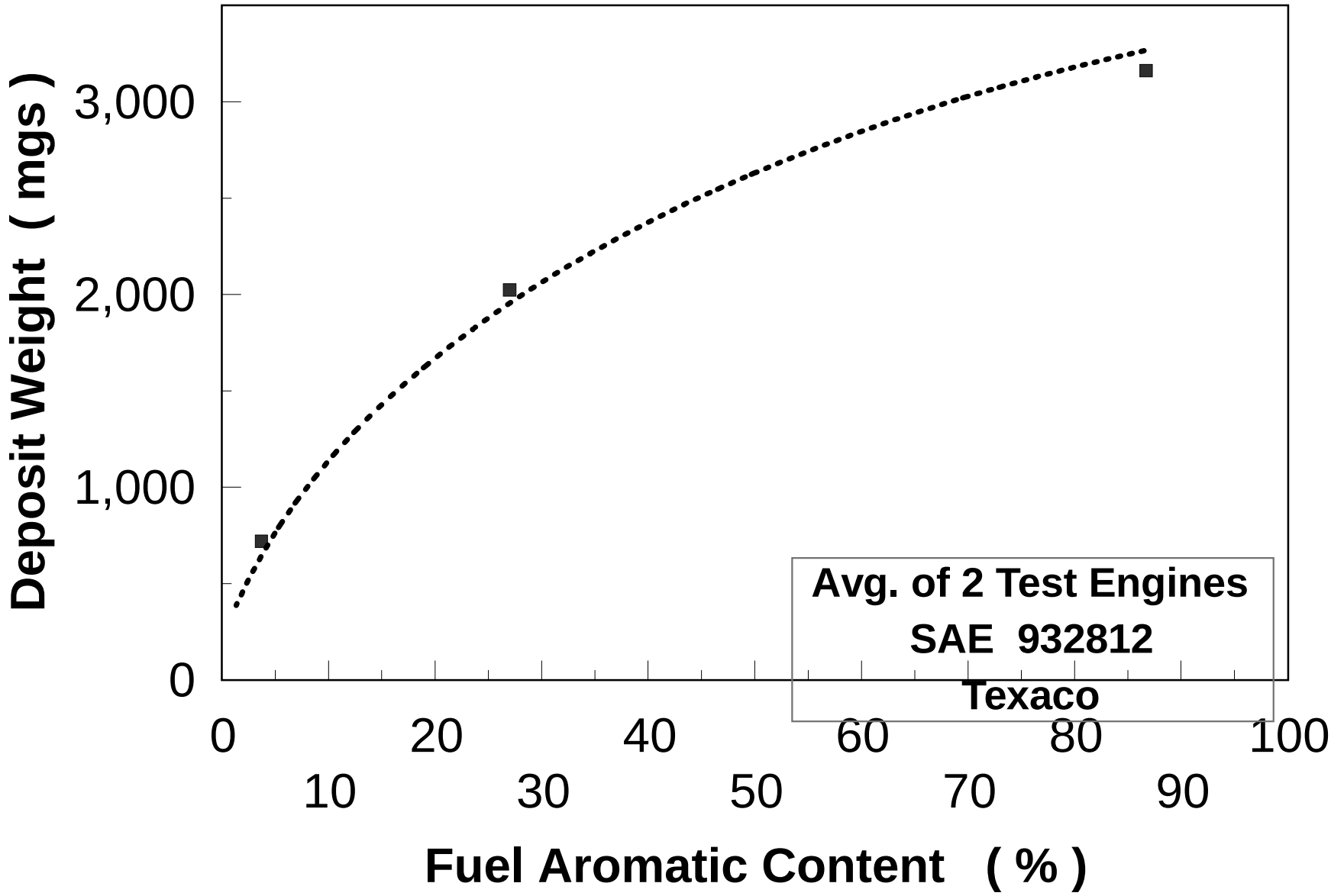


Emissions Increase Mileage Because of CCD* Buildup



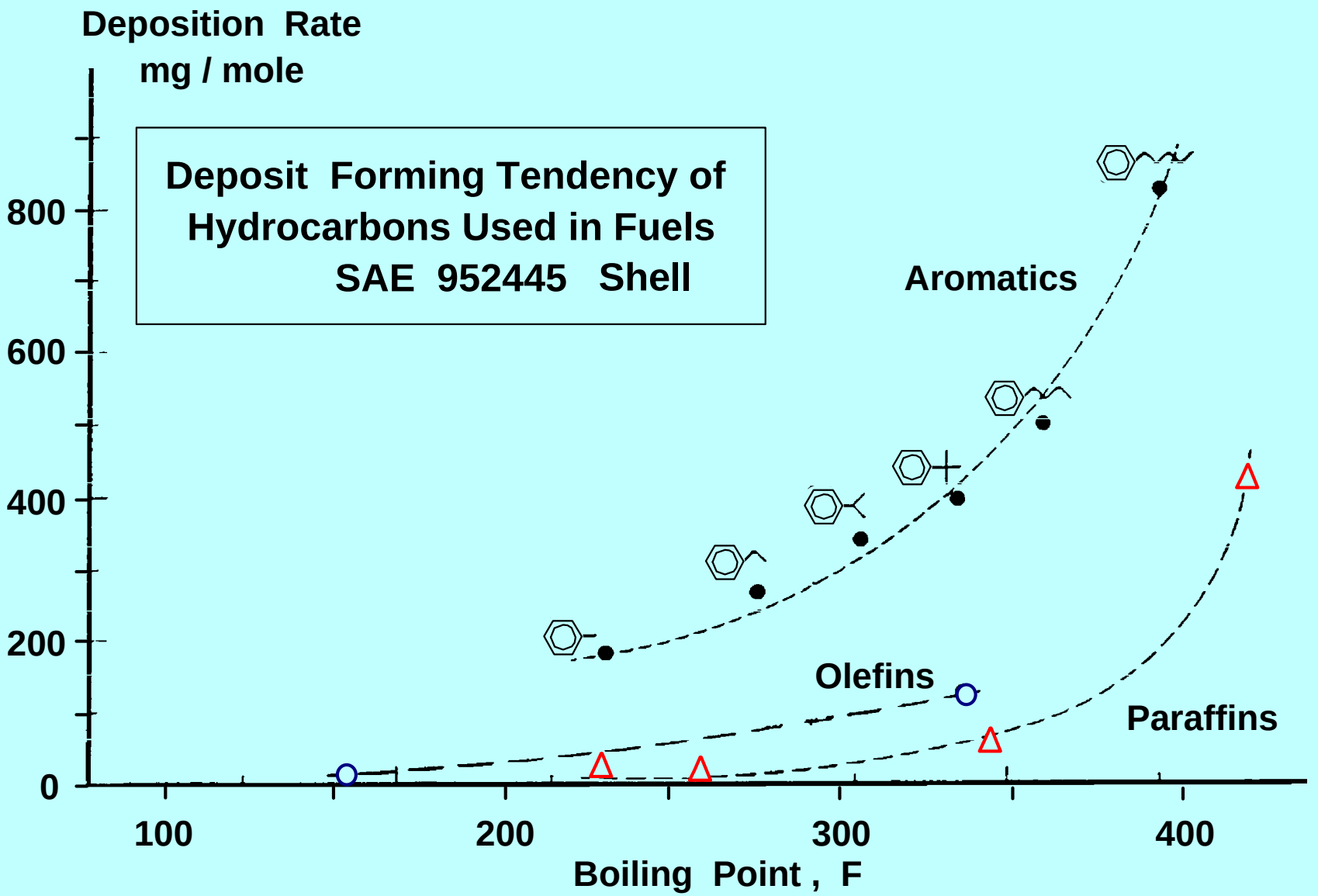
* CCD = Combustion Chamber Deposits

CCD* Buildup increases with Fuel Aromatic Content

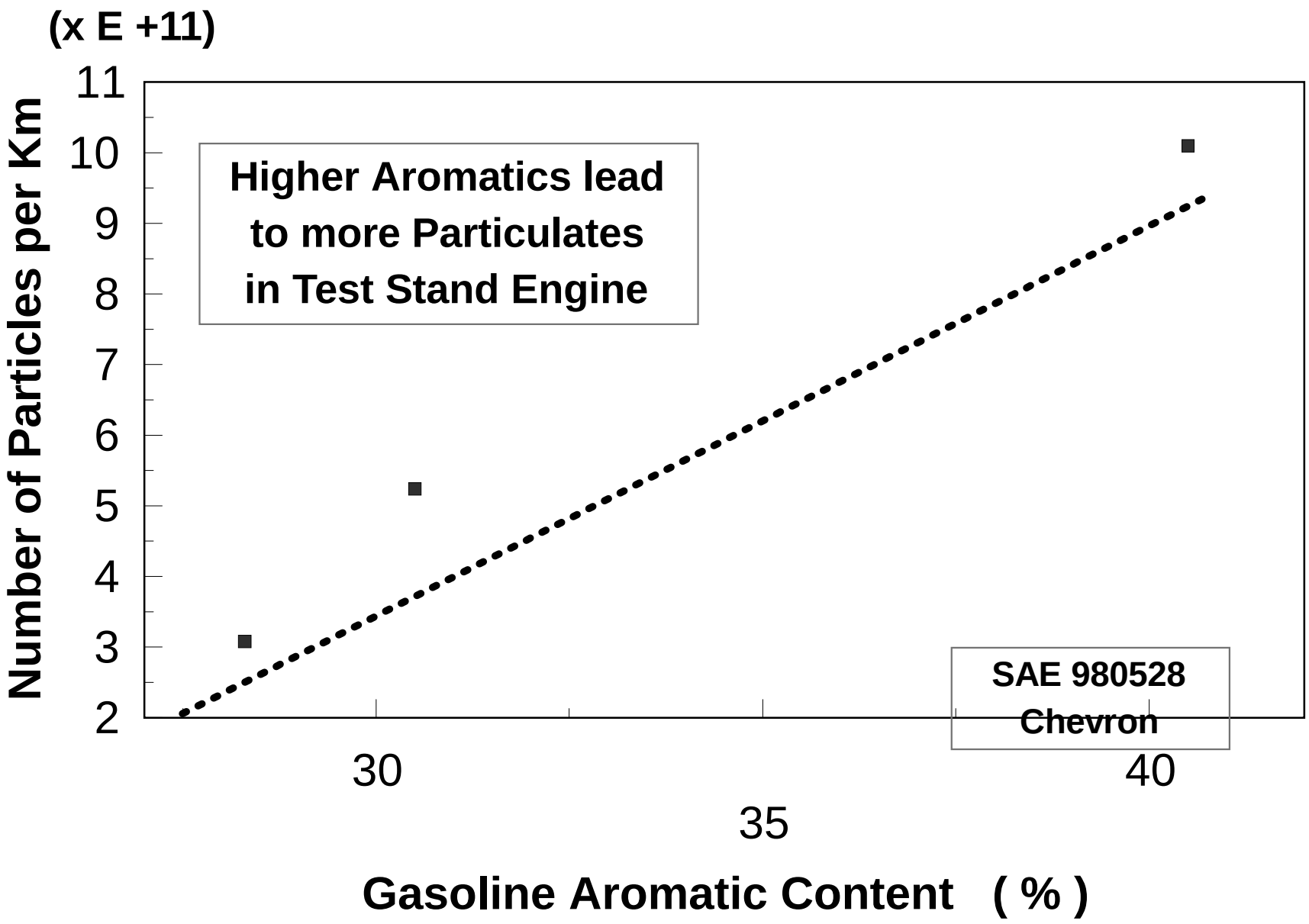


*** CCD = Combustion Chamber Deposits**

Aromatics Highest Contributor to CCD

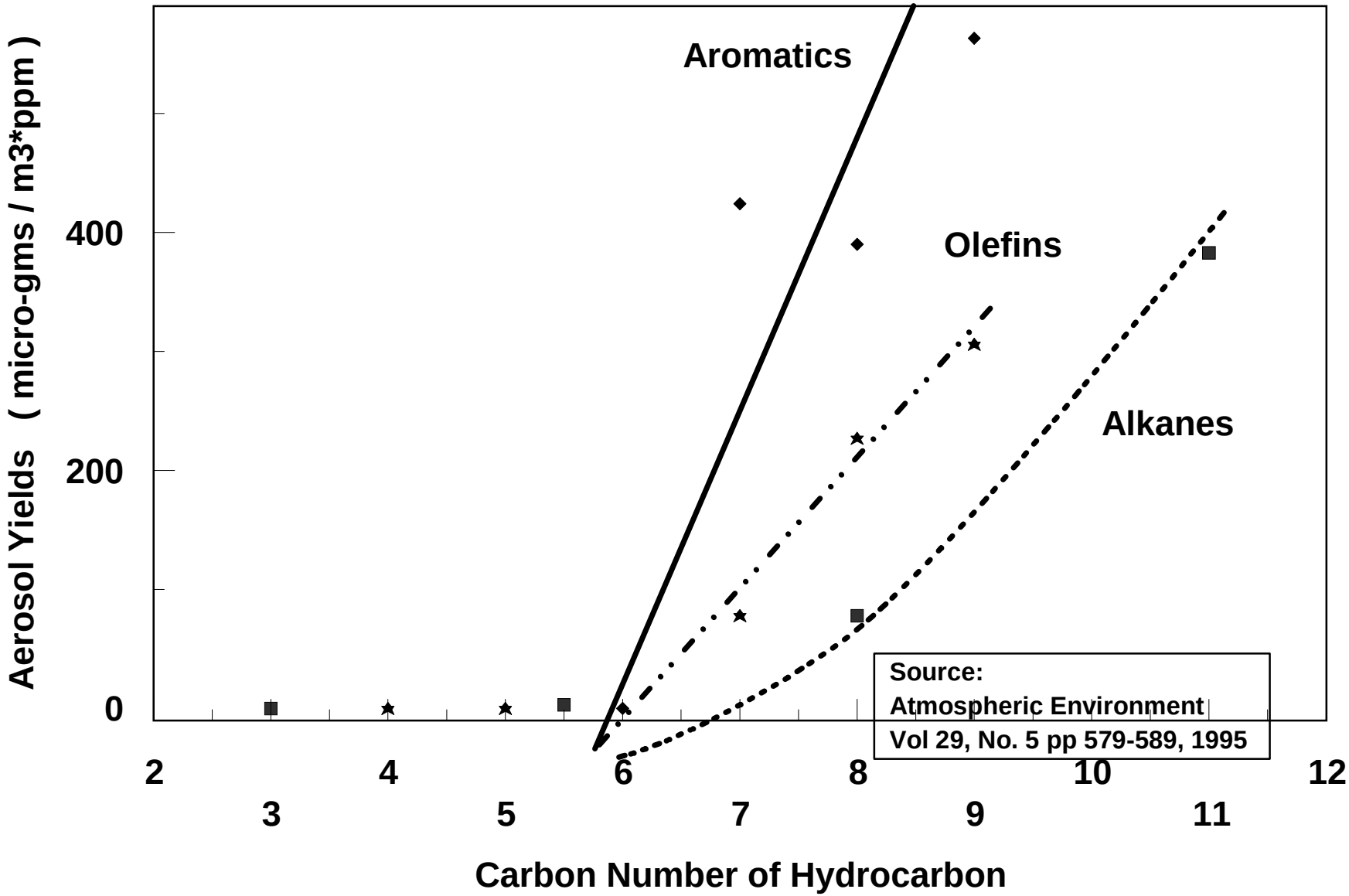


Exhaust Particulates related to Fuel Composition

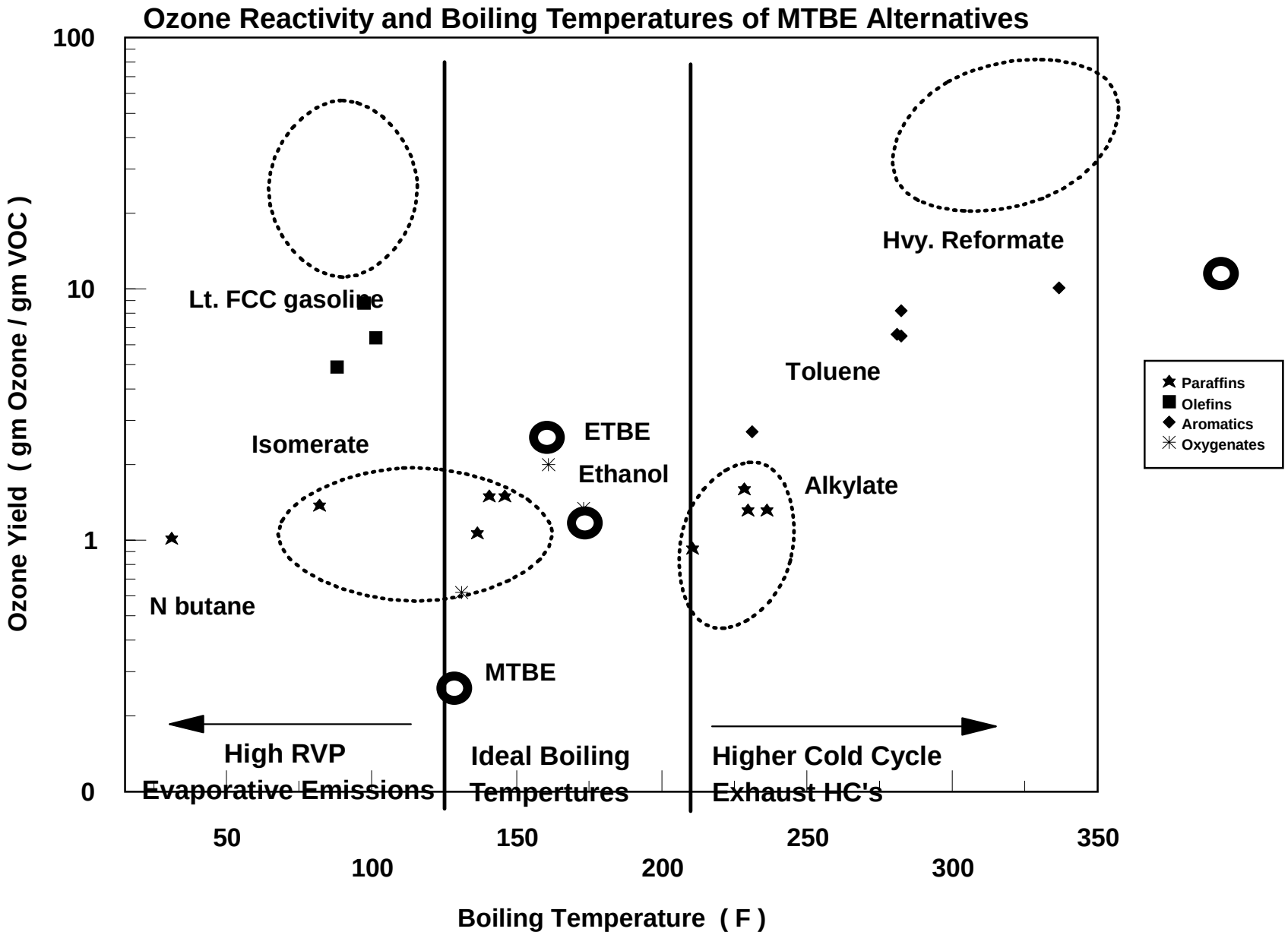


Secondary Aerosols Occur Only With C7+ Compounds

Aromatics in exhaust is the main mobile source of organic PM Aerosols



Alternative Hi-Octane components have less favorable properties than MTBE



Oxygenates Represent Latest Octane Change

Oxygenates are cleaner burning form of octane

RFG with Oxygenates reduces all emissions

- VOC's, NOx & Toxics

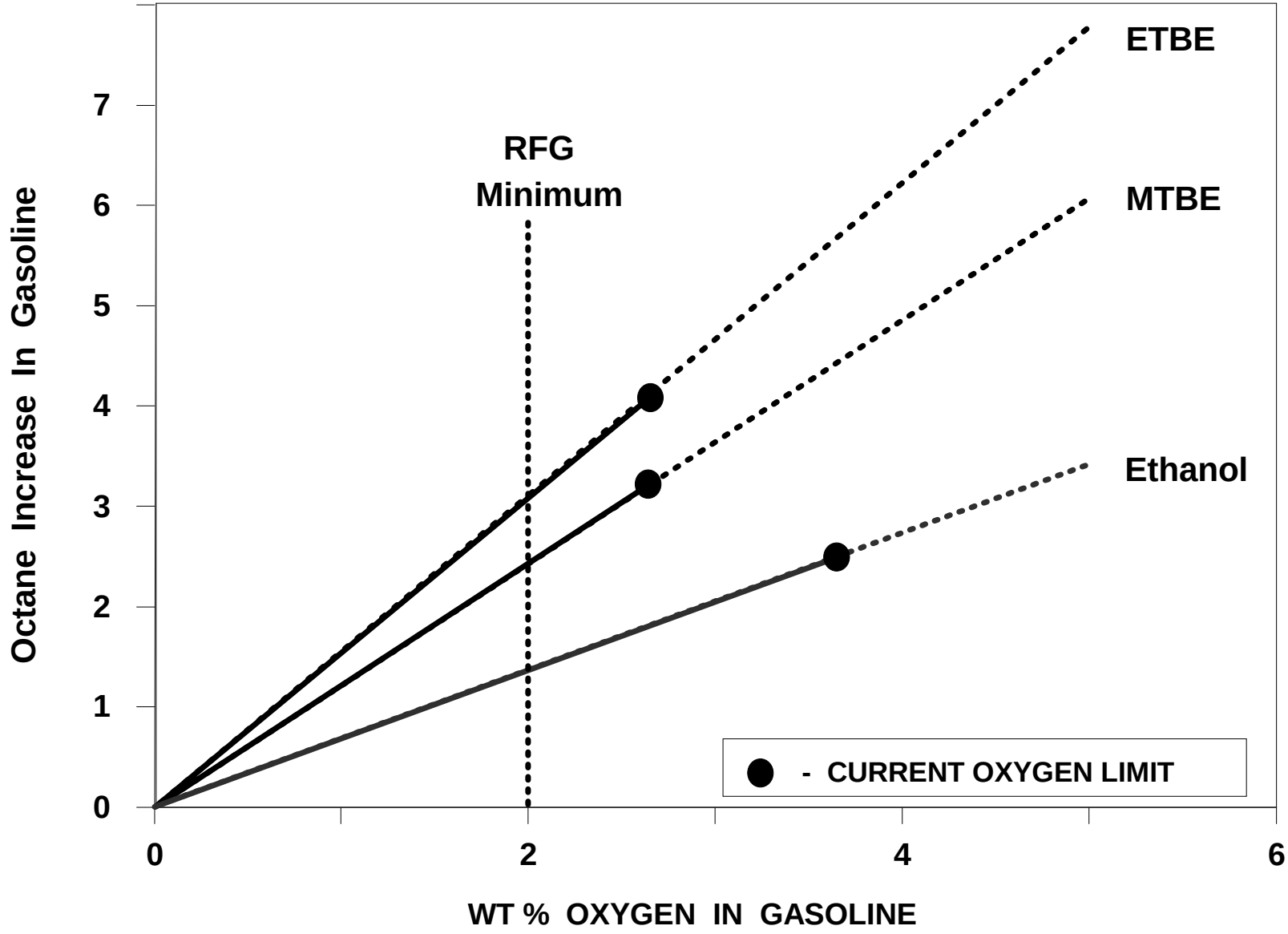
Oxygenates reduce Other Criteria Pollutants

- Lead, CO, SOx & Particulates
- Driveability Performance Improves

Oxygenates, not oxygen, is a key ingredient in RFG

- Oxygen Standard is for requiring the use of oxygenates
- Displaces use of aromatics in Clean Burning Gasolines
- Reduces average boiling point temperature of gasoline
- Without oxygen specification, Fed RFG will have more aromatics

ETHER'S HIGH OCTANE CONTRIBUTION REPLACES MAXIMUM AROMATICS



Ethanol Requires 3.7% Oxygen to match Octane Gain of MTBE at 2% Oxygen

How Does MTBE Work in Federal RFG ?

Federal RFG Phase 1 uses simple recipe

- Max RVP = 7.2 PSIA during summer (South)
- Max Benzene = 1.0 Vol %
- Min Oxygen = 2.0 wt %

11 Vol. % MTBE improves many gasoline properties

- High octane displaces high boiling temperature aromatics
- T50 Distillation drops by 10 to 15 F
- Dilutes many other contaminates (sulfur, olefins, etc.)
- Adds 2 % oxygen to minimize "rich" engine cycles

Results in Cleaner Burning Gasoline

- Vaporizes better during cold cycle
- Decreases Combustion Chamber Deposits
- Reduces unburned HC's during "cold engine cycle"
- Decreases CO emissions & toxics
- Even some NOx reduction
- Reductions in PM & CO2 emissions

U.S. RFG's Exceed Most Fuel Charter Standards

RFG Reduced D.I., Aromatics & Sulfur

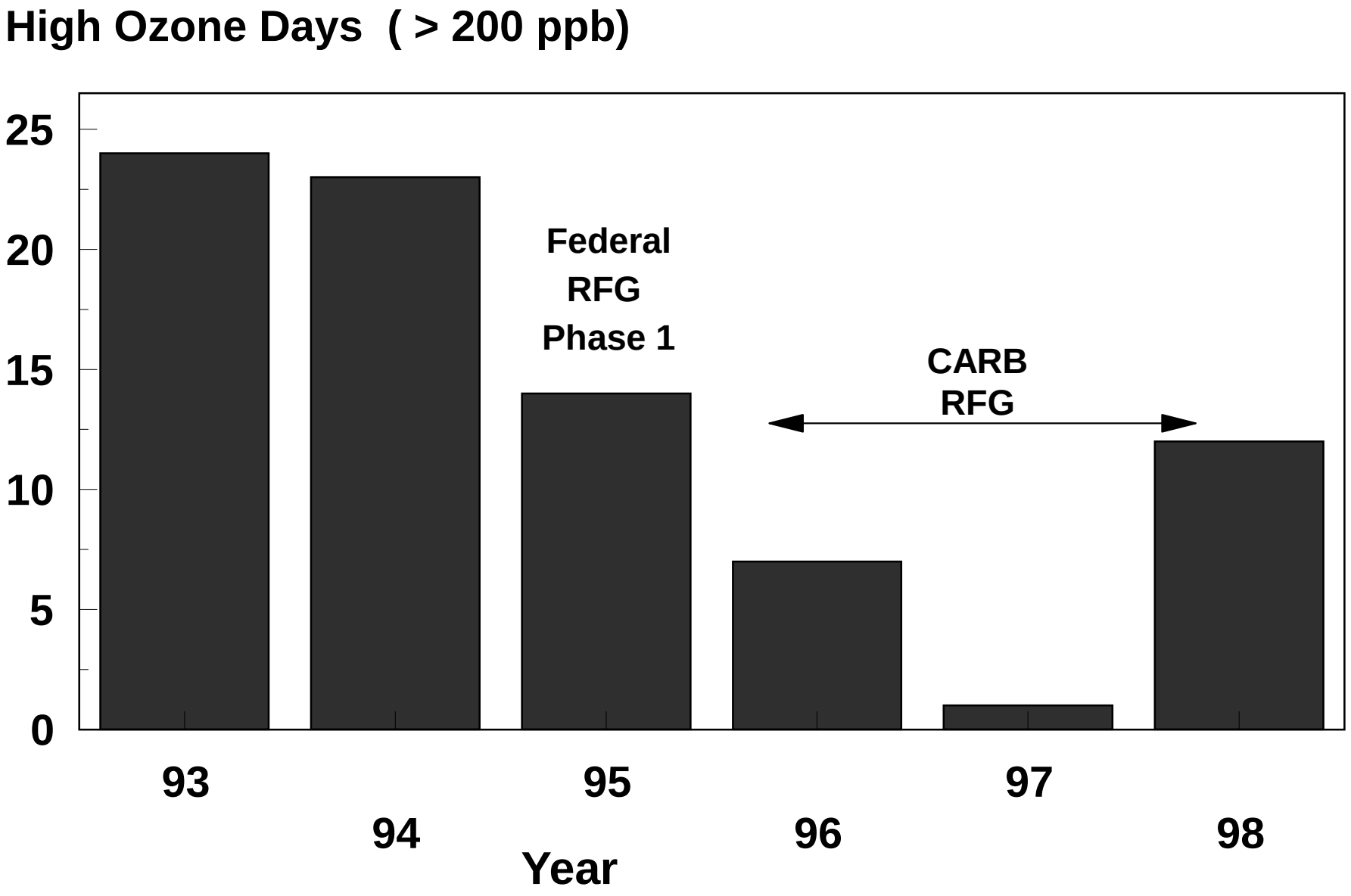
(1997 Avg. of AAMA Summer Fuel Survey)

				CARB RFG	
Volatility	**Conventional**	**Low RVP**	**Fed RFG 1**	**Actual**	**Model Limits**
RVP (PSI)	8.0	7.2	7.6	7.0	*7.0 max*
T50 F	214	223	201	199	*210 max*
T90 F	337	346	335	305	*290 max*
Driv. Index F	1180	1225	1141	1118	*1140 max **
Composition					
Sulfur ppm	309	387	297 *	*20*	*40 max*
Benzene %	1.2	0.9	0.6	*0.5*	*0.8 max*
Aromatics %	30.2	31.3	22.5	*19.5*	*25 max*
Olefins %	9.6	10.8	10.8	3.4	*4.0 max*
Oxygenate V%	1.4	1.1	10.7	9.5	*11 nominal*

* Fed. RFG 2 Sulfur avg < 150 ppm

** Effective Limit by T50 & T90

RFG's Reduced High Ozone Days for Los Angeles Air Basin



Reformulated Gasoline Provides Many Air Quality Benefits

Targeted "FTP" Emissions

Evaporative VOCs, exhaust VOC's, Toxics and NOx

Provides many more "spillover" benefits

Lowers the Ozone Reactivity of Evaporative Emissions
Lowers FTP CO
Reduces build-up of Combustion Chamber Deposits (CCDs)
    Decreases "deterioration rates" for NOx, VOCs and CO
    Decreases primary (exhaust PM emissions)
Lowers secondary aerosols (PM) associated with aromatic oxidation
Reduces fossil CO2 emissions by approximately 2 or more percent
Decreases dependency on crude oil

Both targeted and spillover benefits should be protected

Many benefits associated with high octane oxygenates displacing aromatics

Future formulations need to provide even greater total benefits

There should be no "Back Sliding" on any air quality

SUMMARY REVIEW

Distillation temperatures and aromatic content of gasoline are the key qualities that influence clean combustion

Low distillation temperatures allow "full" vaporization in Cold Engine

Unburned Aromatics oxidize to larger molecules

- **Foul combustion chambers**
- **Contribute to both primary and secondary PM 2.5 inventory**

Data suggest that ethers are superior to aromatics for octane source

- **Ethers (such as MTBE) have many advantages over aromatics**
  - **Reduces CO2 / km**
  - **Lowers CC deposits which reduces NOx emission deterioration**
  - **Reduces part. matter (PM), both primary and secondary aerosols**
  - **Lower boiling point temperature improves vaporization**
  - **Less reactive for "Peak Ozone" formation**

Aromatic and distillation temperature reductions can be more effective than sulfur reductions in decreasing total emissions from existing vehicle fleet